## Environmental Contaminants

Although Rookery Bay and other Aquatic Preserve estuaries are surrounded by extensive state and federal conservation acreage, development and agriculture are situated at locations with critical influence on water quality. The city of Naples and Gordon River sit at the top of the RBNERR boundary with currents bringing contaminants from Naples Bay and the river into Rookery Bay. District VI subbasin, with tributaries into the northern Reserve mangroves, is over 60% developed and still growing. Intensive development lines the middle reach of Henderson Creek – Rookery Bay's main tributary – all with septic tanks when first built, and new golf course communities now line over 1/2 of the Henderson Creek Canal's entire length. Agricultural land makes up 30% of the Collier-Seminole watershed – a subbasin bordering the Tamiami Canal with culverts into coastal estuaries and directly connected to Henderson Creek. Development is spreading into saltmarshes and mangrove fringes to the north of McIlvane Bay.

Metals, pesticides, petroleum products, sewage and fertilizers are the predominant sources of contaminants entering the estuaries managed by the Rookery Bay NERR. Pesticide from mosquito control applications has also been found to deposit within the Reserve. Monitoring of the Reserve's watershed indicates that fenthion (McKenney *et al.*, 1993); chlordane (Brandt-Williams and Shirley, 2000); cadmium, copper, lead, zinc, d-HCH, endosulfan sulfate (Grabe, 1996); metolachlor, atrazine and mercury (Miller *et al.*, 1999) are found in elevated concentrations. RBNERR staff, in partnership with Collier County, the City of Naples, SFWMD and various academic researchers, continue to monitor problem areas in both the estuaries and their watersheds.

## Reducing the Environmental Damage Caused by Mosquito Control Pesticides

Mosquito control has become a necessary part of human existence in Florida. In coastal communities, such as Collier County, the primary target of Mosquito Control Districts are nuisance salt-marsh mosquitoes. Although the salt marsh mosquito is not considered a serious vector of human disease, it can have significant impacts on the economics of an affected area and human quality of life. In Collier County, the primary method to control mosquitoes is to apply pesticides aerially to reduce adult mosquito populations. Two pesticides, baytex and dibrom, are the primary chemicals being used. The pesticide applications typically occur before sunrise, when salt-marsh mosquitoes are most active.

Unfortunately, with the current application technology, pesticides used to control mosquitoes can also unintentionally harm other forms of life (Figure 1). Species such as crustaceans, which are physiologically similar to mosquitoes, are at the greatest risk. For this reason, we used Fiddler Crabs (Figure 2)


**Figure 1.** Using current technology, mosquito control pesticides applied to residential areas can drift and deposit into environmentally sensitive areas like Rookery Bay.

**Figure 2.** Fiddler crabs (*Uca pugilator*) serve as an indicator organism for pesticide contamination.

**Figure 3.** Pitfall traps are used to sample natural fiddler crab populations.

to study the environmental impacts of mosquito control pesticides. The staff of the Rookery Bay National Research Reserve, in conjunction with the Collier Mosquito Control District, has been studying the environmental impacts of mosquito control pesticides for ten years. The goal of this research is not only to identify problems but also to develop solutions that may reduce unnecessary environmental impacts while maintaining effective mosquito control.

## METHODS

This research examined the effects of mosquito control pesticides on the survival of fiddler crabs. Natural fiddler crab abundance was estimated by collecting fiddler crabs using pitfall traps the day after a typical mosquito control application (Figure 3). Pitfall traps were recovered after one day and all the captured crabs were measured and counted.

Field crabs were also collected and placed in cages (Figure 4) to control for confounding natural factors such as predation and tidal cycle and to allow for rapid assessment of pesticide effects. Caged crabs were examined for five days following a mosquito control application and the percent mortality for each group of sixty crabs placed up wind (control site), and at 0.2 miles, 0.5 miles and 1.5 miles down wind was calculated. This study design allowed for an estimate of crab mortality with increasing down wind distance from the pesticide application.

Filter paper placed within the crab's habitat or within empty cages was used to collect pesticide deposition (Figure 5). These chemical analyses were conducted by chemists at Mote Marine Laboratory or Florida A&M University using the same standardized techniques. During the caging studies, we tested the effects of two application nozzle technologies (current and high pressure) and two pesticides (baytex and dibrom) on fiddler crab mortality.

## RESULTS

The current method of controlling mosquitoes caused a significant decrease in the natural fiddler crab populations down wind of the pesticide application area (Figure 6). Natural fiddler crab populations were reduced by up to 95% by current mosquito control applications (Figure 6). Nearly 75% of the pesticide currently applied with the current technology drops to the ground and was wasted (Figure 7). New nozzle technology eliminated this waste (Figure 7). The new nozzle technology also significantly reduced the mortality of fiddler crabs when the pesticide Baytex was used (Figure 8). In addition, the mortality of caged fiddler crabs was reduced to zero when the new nozzle technology was used in combination with the mosquito adulticide, dibrom (Figure 8).

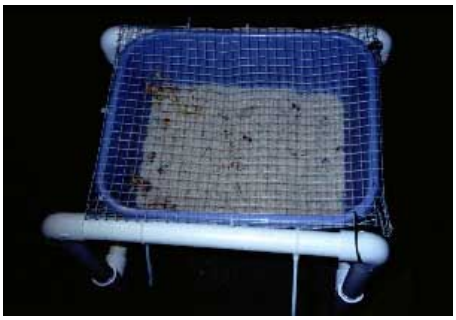

**Figure 4.** Cages are used to hold fiddler crabs during a pesticide application.

**Figure 5.** Filter paper attached horizontally to pesticide collection platforms is used to sample for pesticide deposition.

## Discussion

Research conducted at the Rookery Bay National Estuarine Research Reserve, in cooperation with the Collier Mosquito Control District, has demonstrated that current mosquito control techniques unnecessarily damage the environment. As a direct result of these studies, Mosquito Control Districts across Florida are working together to improve application technologies for controlling adult mosquitoes. These improvements promise not only to reduce environmental damage but also to improve mosquito control at a reduced cost.

A long-term commitment to research and public education is necessary to ensure that mosquito control technologies are continually improved. The public, by influencing local decision-makers, can ensure that the results of this research are used to improve the current mosquito control technology and to encourage the Mosquito Control District to continue this important work.

The current research shows that methods that reduce the size of the pesticide droplets not only improve the effectiveness of a pesticide to kill mosquitoes but also significantly reduce the amount of pesticide needed. Based on our results, the best method to control mosquitoes and reduce environmental damage is to use dibrom and apply it with a nozzle that reduces droplet size. Further research is needed to examine the impact of this recommended application technique on other nontarget species.

Figure 6.

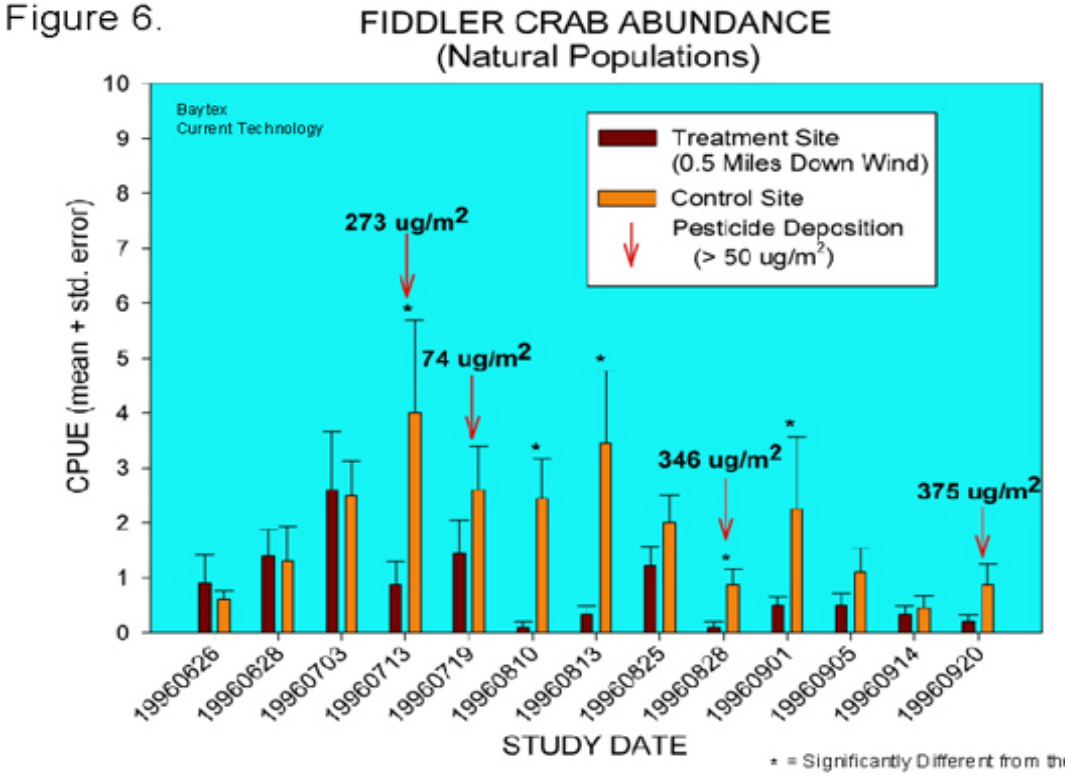

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Figure 7.

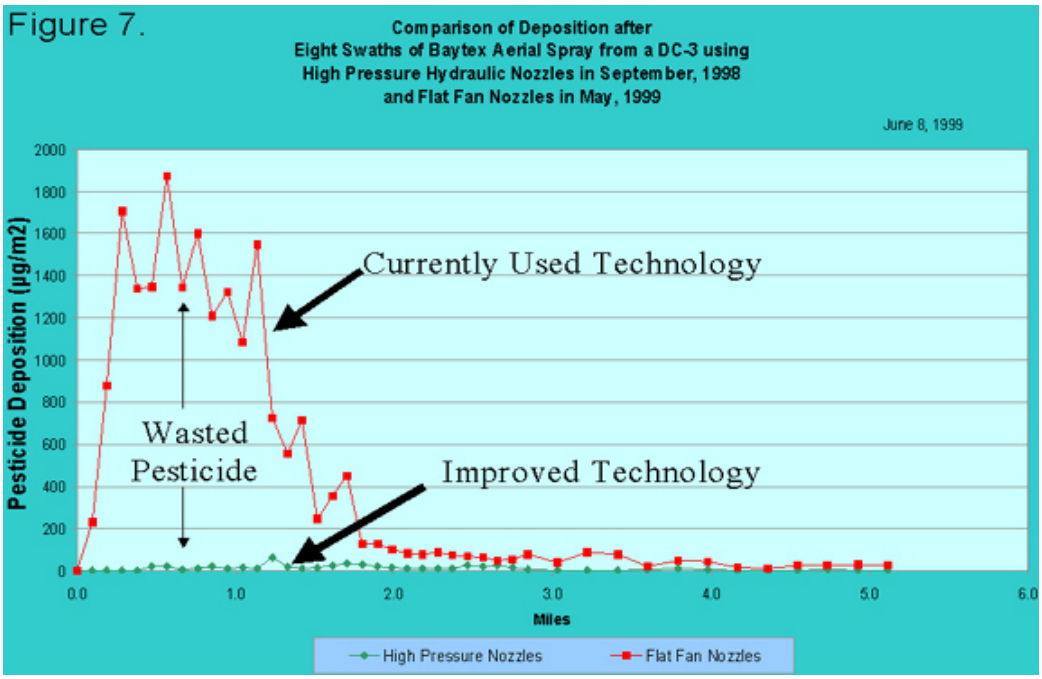
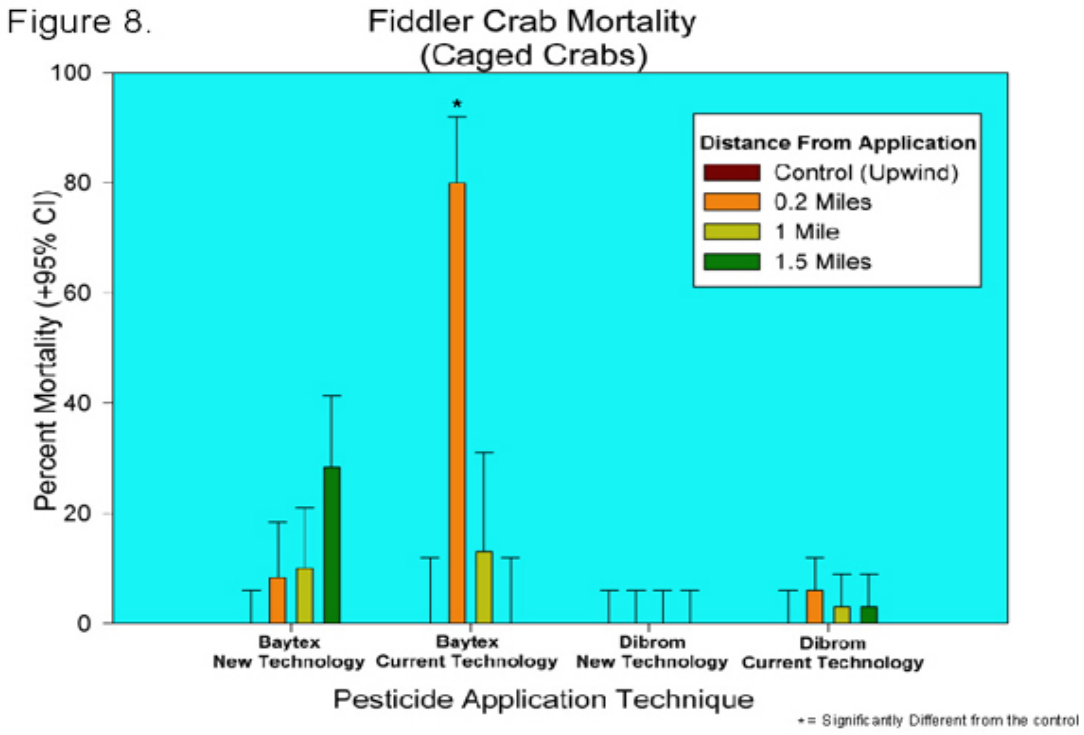



Figure 8.



## Pesticides

Organochlorine pesticides were extensively used in agricultural fields after WWII, and it was not until 1987 that EPA legislation banned sales. DDT, Toxiphene, and Chlordane are a few examples of these compounds. Organochlorines are persistent in soil and sediments, but transfer to the water column both as entrained sediment and via adsorption to dissolved organic carbon (Syracuse Research Corporation 1994). At relatively low concentrations, invertebrate populations in both sediment and water are adversely affected. Bioaccumulation has a detrimental impact on vertebrates as well.

Agricultural fields no longer in production are repositories for these pesticides. As this real estate is converted to residential or is restored, contaminated soils are often flooded. Remobilization of sequestered pesticides is a potential ecological risk for the estuaries downstream, both in the immediate impact on benthic invertebrates, but also in bioaccumulation as wading birds feed in affected areas.

Identifying potential ecological risks as these watersheds are developed is an essential tool for resource management. Several agricultural fields in production prior to 1978 in the District VI, Belle Meade and Southern Golden Gates Estates watersheds are now owned by the State of Florida. These are potential areas of restoration with overland sheet flow as a primary goal.

### Pesticides in RBNERR Canals, Watersheds and Estuaries

The pesticides affecting the area managed by the Reserve can be broadly grouped into two categories. The first category, represented by pesticides such as DDT and chlordane, are no longer in use but, due to their longevity, still are detectable in the watershed. The second category, including fenthion and endosulfan, breakdown quicker and are currently being applied in the watershed. To be effective, sampling for the latter group of chemicals must be closely coupled with application schedules because these chemicals may degrade quickly to levels below detection after causing considerable ecological damage (McKenney *et al.*, 1993). Unfortunately, few studies have coordinated sampling with pesticide application. Therefore, the results of any analyses for shorter-lived pesticides should be viewed with caution.

In a survey of the water quality of the southern Everglades region, Miller *et al.* (1987) also identified a collection site at Tomato Road as having the Reserve's watershed greatest pesticide detection rates. Grabe (1996) found the highest chlordane and d-HCH concentrations yet reported to date in Florida within canals in Collier County. Brandt-Williams and Shirley (2000) also found high levels (maximum = 6100 ppb) of chlordane contamination in sediments collected from fallow agricultural fields within the Reserve's watershed. Shirley *et al.* (1997) detected lower (8 to 10 ppb) concentrations of chlordane in sediment samples collected from canals which drain directly into the Reserve. A more recent analyses found no detectable levels of nineteen organochlorine pesticides, including endosulfan and chlordane, in sediments collected at the headwaters of Henderson Creek and Blackwater River (Savarese *et al.* 2000).

Carter *et al.* (1973) found Faka Union Bay sediments to be approximately three-fold higher in DDE, DDD, and DDT relative to Fakahatchee Bay. Oyster tissue collected from these Bays exhibited lower, yet similar, trends (Carter *et al.*, 1973). In addition to these compounds, Carter *et al.* (1973) found detectable levels of Dieldrin and Myrex in biota collected in the watersheds of these bays. Yokal, (1975) found only trace amounts of DDE in oyster tissue collected from Henderson Creek. Thoemke and Gyorkos (1987) did not detect any organochlorine or organophosphate pesticides in water samples collected from Henderson Creek, Hall Bay or Rookery Bay.

Pait *et al.* (1992), in a survey of the potential pesticide damage to estuaries in the United States,

ranked the Rookery Bay system as having a high level for concern based on estimates of the types (particularly endosulfan) and amounts of pesticides being applied per watershed area. Cantillo *et al.* (1997) reported that the Rookery Bay National Status and Trends site had among the highest nationwide concentration of endosulfan. This is the pesticide most frequently detected in sediments collected from Collier County estuaries (Grabe, 1993). Shirley *et al.* (1997) detected DDD, DDE and chlordane but not endosulfan in sediments collected from Henderson Creek and Blackwater River. Current monitoring has once again detected endosulfan in sediment samples collected in Henderson Creek, Blackwater River and Naples Bay (Shirley *et al.*, unpublished data, summer 2001).

## Metals, Polycyclic Aromatic Hydrocarbons (PAHs), Polychlorinated Biphenyls (PCBs)

Sediments and oyster tissue in Rookery Bay and surrounding managed estuaries show evidence of elevated concentrations of copper, cadmium, lead, zinc, arsenic, mercury and chromium. At least six studies have been conducted between 1973 and the present, with varying levels between bays and over time. Information on PAHs and PCBs in the Reserve and its watershed come primarily from two sources: The NOAA Status and Trend Program and the Collier County Environmental Serrvices Division (CCESD). Although extremely high levels of PAHs have been found in adjacent watersheds in Collier County (Grabe, 1996), the Reserve and its watershed are not currently considered to contain significant levels of these contaminants (CCESD, 1993; Cantillo *et al.* 1997).

**Sediment Data**

The earliest record of sediment heavy metal analyses for the Ten Thousand Islands area are studies conducted in 1972 by Carter et al. (1973) and in 1984 for Rookery Bay, Hall Bay and Henderson Creek by Thoemke and Gyorkos (1987). Since the watershed of these estuaries was relatively undeveloped at the time compared to present conditions, this dataset serves as a valuable baseline for comparison with subsequent heavy metal measurements (Table 1). Even in 1972, Faka Union Bay exhibited elevated concentrations of sediment heavy metals relative to Fakahatchee Bay. Sediment sampling conducted in Rookery Bay, Hall Bay and Henderson Creek during 1984 by Thoemke and Gyorkos (1987) (Table 2) found copper, cadmium, and zinc concentrations similar to those reported for Fakahatchee Bay by Carter et al. (1973). However, lead concentrations reported by Thoemke and Gyorkos (1987) were considerably lower than values reported by Carter et al. (1973).

**Table 1: SEDIMENT HEAVY METAL CONCENTRATION (mean, ppm)**

| | Ni | Zn | Pb | Mn | Cd | Hg | Cu | Cr | As |
|---|---|---|---|---|---|---|---|---|---|
| **FH** | 7.3 | 5.5 | 16 | 17 | nd | 0.44 | 3 | 20.5 | nd |
| **FU** | 20 | 11.2 | 24.3 | 39.9 | 1.2 | 1.42 | 5 | 52.7 | 6.4 |

From Carter et al. (1973) KEY: FU = FAKA UNION BAY, FH = FAKAHATCHEE BAY (nd = not detected).

**Table 2: SEDIMENT HEAVY METAL CONCENTRATION (range, ppm)**

| | Cd | Cu | Pb | Zn |
|---|---|---|---|---|
| **Rookery Bay** | 0.06-.5 | 3-Jan | 2 | 5-Feb |
| **Hall Bay** | 0.04 | 2-Jan | 7-Feb | 5 |
| **Henderson Creek** | 0.07-0.09 | 3 | 4-Mar | 12-Sep |

From Thoemke and Gyorkos (1987)

A more recent sampling effort was conducted by the Collier County Pollution Control Department (CCPCD) (1990 to 1995, Gibson, 1996). The CCPCD sampled and analyzed sediments from Henderson Creek, Rookery Bay, Blackwater River and Faka Union Bay (Table 3). These data were reported as maximum concentrations and suggest decreasing lead and arsenic concentrations in Faka Union Bay. However, since this reporting method lacks means, it is difficult to assess increases in contaminant levels relative to previously reported levels.

Rickabaugh (1999) collected one hundred and sixty-one surficial sediment samples along transects from culverts under US 41 to the nearshore marine environment. These samples were analyzed for Al, Ca, Co, Cr, Cu, Fe, Mn, Ni, Pb, P, S, V and Zn (Table 4). A comparison of these data to Carter et al. (1973) and Thoemke and Gyorkos (1987) indicates that sediment lead concentrations of the Faka Union Bay have stabilized, copper and chromium concentrations may have increased and mercury concentrations have decreased. The Rickabaugh (1999) study illustrates the spatial variability of heavy metal concentrations in this system, with the highest concentrations of chromium (268 ppm), lead (70 ppm) and mercury (0.667 ppm) associated with the sediments adjacent to a marina in the Faka Union Canal and maximum copper concentrations (74.3 ppm) associated with sediments adjacent to the culvert on US 41 west of the intersection with County Road 92. In a survey of surface water contaminants within the southern Everglades region, Miller *et al.* (1999) found the highest mercury concentration (8.3 ng/l) in the Ten Thousand Islands watershed in a canal adjacent to US 41 at the intersection of Tomato Road.

**Table 3: SEDIMENT HEAVY METAL CONCENTRATION (ppm, maximum concentration)**

| | Ag | As | Cd | Cr | Cu | Pb | Zn | Hg |
|---|---|---|---|---|---|---|---|---|
| **Henderson Creek** | 7.5 | 5.6 | 0.7 | 14.4 | 13 | 4 | 13.5 | 0.02 |
| **Rookery Bay** | 1.5 | 2.9 | 1 | 19.2 | 14.8 | 6.5 | 25.9 | - |
| **Blackwater River** | 2.9 | 3.3 | 0.2 | 8.8 | 4.2 | 2.7 | 7 | 0.14 |
| **Faka Union** | 6.2 | 0.8 | 4.3 | 11.7 | 8.8 | 2.5 | 16.2 | 0.04 |

From Collier County Environmental Services Division (1993) and Gibson (1996).

**Table 4: SEDIMENT HEAVY METAL CONCENTRATION (ppm)**

| | Cr | Cu | Pb | Hg |
|---|---|---|---|---|
| Upper Henderson Creek (970381) | 83 | 69.7 | 23 | 0.375 |
| Lower Henderson Creek (970353) | 6 | 1.3 | BDL | 0.154 |
| Upper Blackwater River (9711100) | 31 | 11.2 | 16 | Na |
| Lower Blackwater River (961204) | 43 | 4.8 | BDL | 0.158 |
| Naples Bay (970363) | 14 | 9.5 | BDL | 0.102 |
| Faka Union Bay (961218) | 97 | 8.9 | 21 | 0.337 |
| Pumpkin Bay 961226 | 15 | 2.4 | BDL | 0.138 |

From Rickabaugh (1999) (BDL = Below Detection Limit)

**Bioassay Data**

The National Oceanic and Atmospheric Administration's National Status and Trends (NS&T) Program has collected sediment and oyster tissue from Henderson Creek, Naples Bay and Faka Union Bay annually since 1986 and analyzed these samples for heavy metals, pesticides, polychlorinated biphenyls (PCB), and polycyclic aromatic hydrocarbons (PAH) (Cantillo et al. 1997, Table 5). Unlike other data, these data are "adjusted" by dividing the pollutant concentration by the fraction by weight of sample comprised of silt/clay (< 63 um grain size which precludes direct comparisons with previ-

ously reported data by other investigators. The NS&T program comparison of these sites to the national NS&T average suggests that copper, butyltin, arsenic, chromium and mercury may be elevated in the estuaries managed by the Reserve (Cantillo et al., 1997).

The oyster tissue concentrations reported by the NS&T program for southwest Florida estuaries suggest that Naples Bay and Henderson Creek have elevated copper and arsenic concentrations relative to Faka Union Bay (Table 6). Faka Union Bay and Henderson Creek oyster tissue had nearly twice the concentration of mercury than tissue from oysters collected from Naples Bay.

**Table 5: SEDIMENT HEAVY METAL CONCENTRATION (ppm)**

| | Cu | As | Hg | Pb |
|---|---|---|---|---|
| **Faka Union Bay** | 3.7 | 4.4 | 0.056 | 7.7 |
| **Henderson Creek** | 4.2 | 6.3 | 0.07 | 7 |
| **Naples Bay** | 12 | 5.2 | 0.05 | 6.2 |

From Cantillo *et al.* (1993) (These data are "adjusted" by dividing the pollutant concentration by the fraction by weight of sample comprised of silt/clay)

**Table 6: OYSTER TISSUE HEAVY METAL CONCENTRATION (ppb)**

| | Cu | As | Hg | Pb |
|---|---|---|---|---|
| **Faka Union Bay** | 70 | 8.8 | 0.25 | 0.78 |
| **Henderson Creek** | 170 | 30 | 0.28 | 0.58 |
| **Naples Bay** | 460 | 29 | 0.15 | 0.67 |

From Cantillo *et al.* (1993)